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Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece

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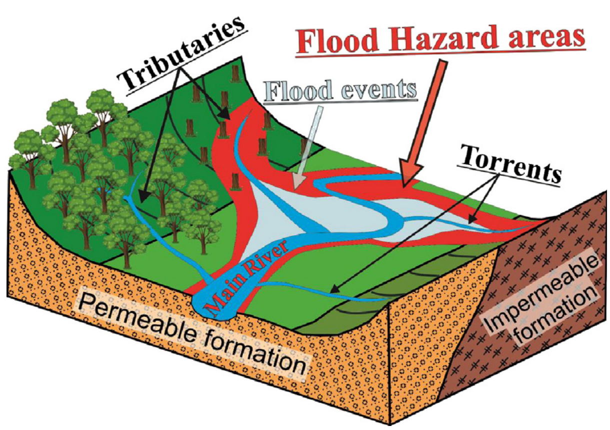
HIGHLIGHTS

- Literature review of spatial, GIS-based methods for flood exposure assessment.
- Development of an index-based methodology to assess the flood hazard areas.
- The methodology analyzes 7 parameters to assess flood exposure.
- Analytical Hierarchy Process is used to estimate the weights of the parameters.
- A sensitivity analysis results to a second more reliable index (FHIS).

GRAPHICAL ABSTRACT



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ABSTRACT

The present study introduces a multi-criteria index to assess flood hazard areas in a regional scale. Accordingly, a Flood Hazard Index (FHI) has been defined and a spatial analysis in a GIS environment has been applied for the estimation of its value.

The developed methodology processes information of seven parameters namely flow accumulation, distance from the drainage network, elevation, land use, rainfall intensity and geology. The initials of these criteria gave the name to the developed method: "FIGUSED". The relative importance of each parameter for the occurrence and severity of flood has been connected to weight values. These values are calculated following an "Analytical Hierarchy Process", a method originally developed for the solution of Operational Research problems. According to their weight values, information of the different parameters is superimposed, resulting to flood hazard mapping. The accuracy of the method has been supported by a sensitivity analysis that examines a range for the weights' values and corresponding to alternative scenarios.

The presented methodology has been applied to an area in north-eastern Greece, where recurring flood events have appeared. Initially FIGUSED method resulted to a Flood Hazard Index (FHI) and a corresponding flood map. A sensitivity analysis on the parameters' values revealed some interesting information on the relative importance of each criterion, presented and commented in the Discussion section. Moreover, the sensitivity analysis

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concluded to a revised index FHIS (methodology named FIGUSED-S) and flood mapping, supporting the robustness of FIGUSED methodology. A comparison of the outcome with records of historical flood events confirmed that the proposed methodology provides valid results.

1. Introduction

Flood is a major natural hazard with often immeasurable impact, affecting annually 170 million people (Kowalzig, 2008). Therefore, flood risk management needs to overcome national borders, geographic location and socio-economic limitations (Degiorgis et al., 2012). Flood risk management is usually divided into flood risk assessment and flood risk mitigation (Schanze et al., 2006). This distinction takes into account apart from the hazard also its impact, since the total elimination of risk is neither possible nor efficient. Indisputably, strategies against floods' impact at a region scale require the identification of prone areas (Tehrany et al., 2013) to provide early warning, facilitate quick response and decrease the impact of possible flood events (Kia et al., 2011).

1.1. Background: literature review

The application of GIS-based multi-criteria analysis in the context of flood risk assessment was rare until 2000. Black and Burns (2002) present an overview of changes in the estimation of flood risk on Scottish rivers with time by re-analyzing flood records. An early attempt to use GIS on water-related hazards has been presented in Meja-Navarro et al. (1994). The risk has been estimated for different hazards (debris, flood) on various zones of Glenwood Springs (Colorado), aiming to define land use suitability. In Correia et al. (1999) GIS is recognized as a powerful means to integrate and analyze data from different sources and flood risk mapping was provided for different scenarios of urban growth, simulating the consequences of alternative cases. In Zerger (2002) relative importance was introduced at the input parameters, underlining the necessity to connect spatial analysis to real-world decision making, thus directing the efforts towards concrete results rather than merely solving technical issues. In Schumann et al. (2000) a GIS-based methodology for rainfall-runoff modeling was developed, while the authors of Liu et al. (2003) incorporated several parameters in their rainfall–runoff model (slope, land use, soil type etc.) in order to estimate the spatial distribution of runoff and the average flow time in river basins. Their aim was to provide insight on river basins' hydrological processes and support flood risk management. In Van Der Veen and Logtmeijer (2005) flood vulnerability was linked with important economic activities for specific areas. The analysis combined economic information of 28 sectors with the borderlines of simulated flood events.

In Forte et al. (2005) the authors expanded an earlier work (Liu et al., 2003) and divided a peninsula in southern Italy into prone zones of different flood risk. They super-imposed GIS layers of both geological and hydrological information. They combined information on the location of karstic sinkholes and information of historical flood events. Thematic maps visualizing this information have been supported by geolithological, permeability and rainfall maps, producing a flood hazard map. Similarly, the authors of Dewan et al. (2007) developed flood hazard maps on Dhaka river basin in Bangladesh, by processing data of the historical major flood event of 1998 and considering the interactive effect of land cover, elevation and geomorphology. The severe flood events of 2000, 2005 and 2006 in Romania urged the generation of flood risk maps (Aldescu, 2008) to support water management experts and flood mitigation.

Flood hazard zones have been delineated for the Tucuman Province (Argentina), using multi-criteria decision analysis Fernández and Lutz (2010). A detailed work on the use of multi-criteria analysis for the estimation of flood vulnerability was also presented in Wang et al. (2011), while in Kourgialas and Karatzas (2011) flood-hazardous areas were estimated by superimposing GIS-layers that visualize spatial and climate information. Sensitive ecosystems and high hazard risk regions in the developing world have been identified in De Sherbinin et al. (2012), considering (among others) the impact of flood by developing a net migration model. In a recent work (Tehrany et al., 2013) 10 parameters have been included in an analysis, with the relative importance of each parameter defined following a statistical analysis. While studying flood hazard in Malaysia (Tehrany et al., 2014) this research group also included the parameter distance-from-river.

The present article deals with the first element of flood risk management, i.e. the definition of flood hazard areas in a specific region. The aim is to identify flood hazard zones, where mitigation measures should be taken. Thus, a spatial, multi-criteria index has been introduced to define such areas. The index was applied in the Rhodope–Evros region in Northern Greece. Although the index is based on the specific geological and Land use characteristics of the study site, it can be modified and applied in other regions.

2. Materials and methods

The authors selected the Rhodope and Evros prefectures in NE Greece as case study for the developed methodology. The study area is located in the north-eastern Greece, comprises the prefectures of Evros and Rhodope and covers an area of 5004 km^2. The northern boundary of the study area is Erythropotamos River which is end up to Evros River. The drainage network is a well-developed with a dendritic form. In the eastern part the torrents and steams end up to Evros River, whereas in the western part (prefecture of Rhodope) end up to Lissos River. The permanent population is about 260,000 and the main economic activities are agriculture and livestock. Forests and agricultural land cover the majority of both two prefectures. The mean slope of the study area is 8%, whereas the mean elevation is 253 m, the maximum elevation of the Rhodope Mountain is 1440 m and the minimum elevation is zero meters in the cost line. A variety of rocks and sediments composes the geological background of the study area. In the mountainous part of the region are placed the impermeable formations which are crystalline rocks such as Amphiboles, Gneiss, Ophiolites, volcanic rocks like Dacites, Ryolites, Andesites. The permeability of these formations increases locally in fault and fracture zones. In contrast, the permeable sediments are located in the lowlands and consist of alluvial deposits, marls, conglomerates, sandstones and sands. Marbles and limestones of the study area are included in the permeable formations due to their karstification. Groundwater is occurred in Fractured (crystalline and volcanic rocks), Karst and porous aquifers. The climate of the area is continental and is characterized by hot and dries summers and harsh and wet winters with large periods of snow.

This specific location encloses 10 sub-basins and was selected because of its evident flood susceptibility, justified by recurrent flood events (Ramos and Thielen, 2006); (Angelidis et al., 2010). Only during the last 10 years major flood events occurred in 2005, 2006, 2010 and 2015. Flooding in 2005 and 2010 was so severe that the authorities had no other option than to explode dikes in order to relief the flood wave. The most recent events of February 2015 resulted in 20,000–30,000 hectares of farm land being flooded and a huge impact to the local economy. Once again the necessity to prevent flood waves from